IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application Number	:	10/507,306	Confirmation No. 9075
Applicant	:	Horst ZIMMERMANN, *et al.*	
Filed	:	March 23, 2003	
Title	:	OPTICAL FIBER RECEIVER HAVING AN INCREASED BANDWIDTH	
TC/Art Unit	:	2878	
Examiner:	:	Tony KO	
Docket No.	:	60291.000025	
Customer No.	:	**21967**	

SUBMISSION OF SUBSTITUTE SPECIFICATION
UNDER 37 C.F.R. §§ 1.52; 1.121(b)(3); and 1.125

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Responsive to the Examiner Ko's phone call of March 8, 2007, the following are provided:

Substitute Specification (clean copy) as Attachment A; and
Substitute Specification (marked-up copy) as Attachment B.

Applicants believe that no fees are required for entry of this response because it is submitted within two months of the mailing date of the Notice. However, in the event of any variance between the fees determined by Applicants and those determined by the U.S. Patent and Trademark Office, please charge any such variance to the undersigned's **Deposit Account No. 50-0206**.

In the Specification:

Please substitute the specification in the above-referenced patent application with the substitute specification provided in Attachment A.

Remarks

Applicants submit this Substitute Specification (Attachment A) in response to the Examiner Ko's phone call of March 8, 2007. By this Substitute Specification, Applicants have incorporated amendments to the specification, which were included in the RCE Submission under 37 C.F.R. §1.114 filed February 28, 2007. Applicants respectfully submit that no new matter has been introduced in this substitute specification pursuant to 37 C.F.R. § 1.125(b).

Pursuant to 37 C.F.R. § 1.125(c), a marked-up copy of the Substitute Specification showing the changes to the specification is included as Attachment B.

Conclusion

It is believed that no additional fees are due in connection with the filing of this Substitute Specification. However, in the event of any variance between the fees determined by Applicants and those determined by the U.S. Patent and Trademark Office, please charge any such variance to the undersigned's **Deposit Account No. 50-0206**.

Respectfully submitted,
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Dated: March 9, 2007

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ATTACHMENT A

Substitute Specification (clean copy)

Optical fibre receiver with increased bandwidth

The invention concerns a (monolithic) integrated optical fibre receiver with an increased sensitivity and increased bandwidth.

Known optical fibre receivers consist primarily of a photodiode and of a transimpedance amplifier which converts the current from the photodiode into a proportional voltage. See, for instance, DE 32 33 146 (AT&T Technologies) or DE 33 38 024 (SEL AG). A decision circuit may also follow, whose task is to decide whether the light level being received corresponds to a logical zero or to a logical one. Optical fibres with larger diameters produce a light spot that is correspondingly large. When, for instance, plastic fibres are used, the spot of light that is to be received can be, relatively, very large (up to one millimetre in diameter). In order to be able to fully exploit the incoming light flux, the photosensitive surface of the receiving photo diode is correspondingly modified. However, with the increase in receptive area, the depletion layer capacitance of a photo diode also rises, resulting in a deterioration both of its speed and of the noise behaviour of the subsequent transimpedance amplifier.

A technical problem addressed by the invention is that of providing a relatively large light-sensitive receptive area for fast optical signals, and yet to increase the bandwidth and the sensitivity of the optical receiver.

This challenge is answered, in accordance with the invention, by dividing an optical receiver diode whose size has been adapted to that of the spot of light, and by following each individual partial photodiode with its own transimpedance

amplifier . The output signals from the individual (separate) transimpedance amplifiers are integrated in a summing amplifier.

Because the partial photodiodes have a lower depletion layer capacitance than a larger diode whose area corresponds to the total, the individual transimpedance amplifiers have a wider bandwidth and a better noise behaviour. These properties are only insignificantly affected by the summing amplifier.

The principle of division of an optical receiver can also be implemented in bipolar and BICMOS OEICs. Due to the higher level of amplification, these can achieve data rates even higher than 622 Mbit/s with an effective diameter of have 1 mm for a photo diode.

These high data rates can for the first time be achieved with the aid of the photodiode division principle, in combination with an effective photodiode diameter of up to 1 mm. In this way an optoelectronic integrated circuit (OEIC) for a plastic fibre with a diameter of around 1 mm can achieve a data rate of more than 500 Mbit/s.

A further possible application lies with optical receivers for glass fibres or for plastic fibres that permit a high tolerance in the adjustment of plug-in optical connectors, or which do not require adjustment.

The invention will be explained with the aid of example implementations. All the elements illustrated should be a understood as having been manufactured by integrating them onto one chip in CMOS technology, unless described otherwise.

Figure 1 shows a view from above of a photodiode in an optical fibre receiver according to the prior art (schematic).

Figure 2 shows the circuit of a photodiode with a transimpedance amplifier 29.

Figure 3 shows a view from above of a photodiode in an example of the optical fibre receiver in accordance with the invention (schematic).

Figure 4 shows a circuit in accordance with the invention with partial photodiodes and with a number of transimpedance amplifiers and the summing amplifier.

Figure 5 is a vertical section through the PIN photodiode according to Figure 3 (schematic).

Figure 6 is a diagram of the input noise density plotted against the frequency.

The full-area photodiode D in Figure 1, manufactured in 0.6 pm CMOS technology, has a diameter "dl" of 400 pm and a depletion layer capacitance of about 1.6 pF. The four partial photodiodes Dl, D2, D3 and 04 in Figure 3 (each) have a depletion layer capacitance of 400 fF. An electrical contact 10 to the photodiodes to the rear of the substrate (see Figure 5 with section A-B from Figure 3) considerably reduces the series resistance of the PIN diodes.

The transimpedance amplifiers 20 to 23 in accordance with Figure 4 have a transimpedance of 70 kOhm, while the summing amplifier 30 has an amplification factor of 2.5. The bandwidth of the transimpedance amplifier 29 associated with the full-area photodiode D according to Figures 1 and 2 is 151 MHz, while that of the total system involving four

divided photodiodes 11 in accordance with Figures 3 and 4 having the same receiver area is 402 MHz.

The transimpedance of the total system with four divided photodiodes in accordance with Figure 4 is 164 kOhm.

The electrical circuitry connecting the individual photodiodes Dl to D4 can be seen in Figure 4. One of the amplifiers 20 to 23 is allocated to each of the partial diodes and accepts its electrical output signal. Through a circuit configuration as current-voltage converters with feedback resistance Rf, each of the individual transimpedance amplifiers is responsible for one partial diode. The output signals are not illustrated separately, but are present at the input resistor R1 of the summing circuit 30, which, through its feedback resistor R2, determines the amplification factor of the summing circuit. In the illustration above, this has been selected to be 2.5.

The structure of the individual diodes in accordance with Figure 3 can be seen in the sectional diagram of Figure 5. The two photodiodes Dl and D2 seen through section A-B appear as Photodiode 1 and Photodiode 2, and their N+ regions are separated by a narrow strip 12. This cathode region is unique for each photodiode, and is connected to the associated amplifier in accordance with Figure 4. The relevant anode connection of a partial diode is made to the P+ region above the P well and the buried P+ layer in the epitaxial layer, and on the both sides of the N+ layer of each photodiode Dl and D2. The anodes can be connected to ground.

A further anode 10 on the rear of the substrate can significantly reduce the series resistance of the diodes.

Figure 5 is only a section of an integrated circuit which can extend further to the left and to the right, in particular including integrated circuit amplifiers as they are indicated on Figure 4, or also further optical fibre receivers. Each optical fibre receiver here is coupled through an electrical plug-in connector to an optical fibre - not shown - in order to project a light spot from the optical fibre onto the optical fibre receiver of Figure 3. The size of the spot of light can be seen in the sectional view for the two partial diodes Dl and D2.

It should of course be clear that the figure given for the diameter is an approximate value, and that it does not necessarily have a circular shape, as its name suggests. The corresponding diagram shows in Figure 1 and Figure 2 a form having a number of corners which approximates largely to a circular shape but which recognises aspects of production technology relevant to optimised manufacture in integrated form.

After connecting the individual diodes Dl to D4 to their corresponding transimpedance amplifiers 20 to 23, the anode terminals of the diodes are joined to a common potential. The cathode terminals of the diodes are each independently connected to one input of the transimpedance amplifiers that electrically convert or amplify the signals, in preparation for subsequent electrical combination in the summing circuit 30. On the basis of Figure 5, no highly electrically conductive connection is provided between anode and cathode 1 or between anode and cathode 2 of the two photodiodes Dl and D2, which means that the two connections are not joined by an electrically conductive coupling. This only changes for one

of the connections of each diode after they are configured in accordance with Figure 4.

Figure 6 compares the equivalent input noise densities of the following systems :

(a) a full-area photodiode D with one transimpedance amplifier;

(b) a partial photodiode D1 with one transimpedance amplifier and

(c) four partial photo diodes, each having its own transimpedance amplifier followed by addition in summing amplifier 30.

If the input noise densities are integrated over the range 1 MHZ to 150 MHz, the following values are obtained for the equivalent input noise densities: for the full-area photodiode with one transimpedance amplifier we obtain 59.3 nA, while for the four divided photo diodes 11 with four transimpedance amplifiers and a summing amplifier, the figure is 33.5 nA.

By dividing the four photodiodes, the bandwidth can be more than doubled, while the equivalent input noise current with constant bandwidth can be almost halved.

The bandwidth of the whole system, 402 MHz, is enough to process a non-return-to-zero (NRZ) data rate of 500 Mbit/s or of 622 Mbit/s.

For a photodiode with a diameter "d2" of 1 mm, the depletion layer capacitance is 8.8 pF. One of the four partial photo diodes therefore has a depletion layer capacitance of 2.2 pF. For the four equally divided photo diodes, we reach with a transimpedance of 164 kOhm a bandwidth of 116 MHz, which is sufficient for a data rate of 155 Mbit/s. If the feedback

resistor Rf in the amplifiers 20 to 23 is reduced, then at a transimpedance of 32.6 kOhm a bandwidth of 413 MHz (corresponding to a data rate of 622 Mbit/s) is achieved.

These data rates can for the first time be achieved with the aid of the photodiode principle, in combination with an effective photodiode diameter of 1 mm. In this way an optoelectronic integrated circuit (OEIC) for a plastic fibre with a diameter of 1 mm can achieve a data rate of more than 500 Mbit/s.

A further possible application lies with optical receivers for glass fibres or for plastic fibres that permit a high tolerance in the adjustment of plug-in optical connectors, or which do not require adjustment.

ATTACHMENT B

Substitute Specification (marked-up copy)

Optical fibre receiver with increased bandwidth

The invention concerns a (monolithic) integrated optical fibre receiver with an increased sensitivity and increased bandwidth.

Known optical fibre receivers consist primarily of a photodiode and of a transimpedance amplifier which converts the current from the photodiode into a proportional voltage. See, for instance, DE 32 33 146 (AT&T Technologies) or DE 33 38 024 (SEL AG). A decision circuit may also follow, whose task is to decide whether the light level being received corresponds to a logical zero or to a logical one. Optical fibres with larger diameters produce a light spot that is correspondingly large. When, for instance, plastic fibres are used, the spot of light that is to be received can be, relatively, very large (up to one millimetre in diameter). In order to be able to fully exploit the incoming light flux, the photosensitive surface of the receiving photo diode is correspondingly modified. However, with the increase in receptive area, the depletion layer capacitance of a photo diode also rises, resulting in a deterioration both of its speed and of the noise behaviour of the subsequent transimpedance amplifier.

A technical problem addressed by the invention is that of providing a relatively large light-sensitive receptive area for fast optical signals, and yet to increase the bandwidth and the sensitivity of the optical receiver.

This challenge is answered, in accordance with the invention, by dividing an optical receiver diode whose size has been adapted to that of the spot of light, and by following each individual partial photodiode with its own transimpedance

amplifier . The output signals from the individual (separate) transimpedance amplifiers are integrated in a summing amplifier.

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These high data rates can for the first time be achieved with the aid of the photodiode division principle, in combination with an effective photodiode diameter of up to 1 mm. In this way an optoelectronic integrated circuit (OEIC) for a plastic fibre with a diameter of around 1 mm can achieve a data rate of more than 500 Mbit/s.

A further possible application lies with optical receivers for glass fibres or for plastic fibres that permit a high tolerance in the adjustment of plug-in optical connectors, or which do not require adjustment.

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The full-area photodiode D in Figure 1, manufactured in 0.6 pm CMOS technology, has a diameter "dl" of 400 pm and a depletion layer capacitance of about 1.6 pF. The four partial photodiodes Dl, D2, D3 and 04 in Figure 3 (each) have a depletion layer capacitance of 400 fF. An electrical contact 10 to the photodiodes to the rear of the substrate (see Figure 5 with section A-B from Figure 3) considerably reduces the series resistance of the PIN diodes.

The transimpedance amplifiers 20 to 23 in accordance with Figure 4 have a transimpedance of 70 kOhm, while the summing amplifier 30 has an amplification factor of 2.5. The bandwidth of the transimpedance amplifier 29 associated with the full-area photodiode D according to Figures 1 and 2 is 151 MHz, while that of the total system involving four

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The electrical circuitry connecting the individual photodiodes Dl to D4 can be seen in Figure 4. One of the amplifiers 20 to 23 is allocated to each of the partial diodes and accepts its electrical output signal. Through a circuit configuration as current-voltage converters with feedback resistance Rf, each of the individual transimpedance amplifiers is responsible for one partial diode. The output signals are not illustrated separately, but are present at the input resistor R1 of the summing circuit 30, which, through its feedback resistor R2, determines the amplification factor of the summing circuit. In the illustration above, this has been selected to be 2.5.

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A further anode 10 on the rear of the substrate can significantly reduce the series resistance of the diodes.

Figure 5 is only a section of an integrated circuit which can extend further to the left and to the right, in particular including integrated circuit amplifiers as they are indicated on Figure 4, or also further optical fibre receivers. Each optical fibre receiver here is coupled through an electrical plug-in connector to an optical fibre - not shown - in order to project a light spot from the optical fibre onto the optical fibre receiver of Figure 3. The size of the spot of light can be seen in the sectional view for the two partial diodes Dl and D2.

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The bandwidth of the whole system, 402 MHz, is enough to process a non-return-to-zero (NRZ) data rate of 500 Mbit/s or of 622 Mbit/s.

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